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COLORADO STATE UNIV FORT COLLINS  
INSTRUMENTATION FOR VEHICLE MOBILITY TESTING IN A TROPICAL ENVI--ETC(U)  
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TROPICAL ENVIRONMENT

COLORADO STATE UNIVERSITY,  
FORT COLLINS, COLORADO

JUNE 1966

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Contract Report No. 3-154

COLORADO STATE UNIVERSITY  
THAILAND TRAFFICABILITY INSTRUMENTATION TEAM

Technical Report

Instrumentation for Vehicle Mobility Testing  
in a Tropical Environment

under contract with  
Department of the Army  
Waterways Experiment Station  
Vicksburg, Mississippi  
and

Advanced Research Projects Agency (OSD)

Contract No. DA-22-079-eng-378 (Negotiated)

S. J. Clark, Assistant Professor  
Department of Agricultural Engineering  
Campus Coordinator for Project

Colorado State University  
Fort Collins, Colorado

June 1966

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## ACKNOWLEDGMENTS

The author wishes to express appreciation to the Advanced Research Projects Agency and the Waterways Experiment Station for the support which permitted this work to be carried out.

The author would also like to take this opportunity to thank John Pope, Harry Leiby and Hillar Ilves for their assistance in preparing this report.

## INTRODUCTION

Under the terms of contract No. DA-22-079-eng-378 (Neg.) with the Waterways Experiment Station, Vicksburg, Mississippi, Colorado State University agreed to provide technical assistance to the Advanced Research Project Agency in Thailand. This assistance included:

1. The design of instrumentation and associated systems for research and development testing related to vehicular trafficability
2. Fabrication, installation, operation, and maintenance of the above systems
3. The development of testing procedures
4. The collection, reduction, and compilation of test data
5. The preparation of technical reports
6. The training of local technicians to perform similar tasks

To provide the above assistance Colorado State University provided a three-man instrumentation team which included:

1. John V. Skinner, Instrumentation Engineer
2. Harry B. Leiby, Technician
3. Robert H. Horth, Junior Research Engineer

The University also furnished a campus coordinator and secretary on a part time basis. Richard T. Shen served as the campus coordinator until 1 August 1965 when he accepted an assignment in Brazil. His vacancy was filled by the author of this report.

This contract was initiated 15 August 1963 and terminated 14 August 1965. An outline of the team accomplishments during this period is presented below in sequence:

1963

October Two members of CSU team arrived in Bangkok and settled in  
November Third CSU team member arrived in Bangkok  
Drew plans for instrument calibration  
Made instrumentation for hand penetrometer and bevameter  
Assisted in radio wave reflection calculation  
December Observed field testing of "Jiger"

1964

January Designed a low pressure transducer  
Assisted in installation of engine hour meters on Power Wagon  
Assisted in preparations of proposed drawbar pull test procedure  
February Started "fifth" wheel universal joint drawings  
Designed and made shop drawings of platform scales  
Tested the low pressure transducer  
March Finished "fifth" wheel universal joint drawings  
Fabricated base of platform scales  
Completed calibration unit for hand bevameter and penetrometer  
Attempted unsuccessfully to regulate voltage on gasoline generator  
Tested a DC-AC converter  
Designed brass weights for calibrations  
Calibrated bevameter force transducer  
Tested tension and shear in three wood specimens and their kinetic energy absorption  
Designed wood armor test section forms  
Designed clevises for SEATO tension-compression machine for large force transducer calibration  
April Designed driver simulation platform  
Designed orthogonal accelerometer mountings  
Designed mountings for accelerometers on "vehicles suspension, axle, etc."  
Designed aluminum gasoline tank with a fuel level indicator  
Completed calibration and recording system for driver simulation platform  
Completed bevameter torque and displacement transducers and calibrated platform scales  
May Completed calibration of bevameter torque and displacement transducers  
Completed instrumentation of Power Wagon  
Assisted in fuel consumption and vibration tests at Hua Hin  
Instrumented Hover Truck for drawbar  
Aided Program Manager in Surveillance on redesign of electronic intrusion alarm system

- June Fabricated and calibrated a graduated fuel container  
Took accelerometer and fuel flow data for Power Wagon and reduced the data  
Participated in soil tests  
Designed and fabricated a calibration box  
Finished and calibrated three dynamometers  
Designed and fabricated Power Wagon wheel revolution counters  
Assisted Surveillance on electronic intrusion alarm system  
Obtained data on Hover Truck: fuel consumption, acceleration, drawbar pull, wheel slip, and soil strength
- July Comparison tests of Hover Truck and Land Rover: drawbar pull, vibration, gas consumption, and soil tests  
Reduced this data  
Repaired and calibrated two soil moisture meters  
Designed wheel cams for Power Wagon and 3/4 ton truck  
Experimented with an instrumented roll and pitch measuring system
- August Completed Power Wagon and 3/4 ton truck instrumentation  
Conducted drawbar pull tests on the above  
Designed rolling resistance measurement brackets for Spryte  
Completed a six channel calibrator unit for transducers  
Repaired and recalibrated a flow meter
- September Conducted Power Wagon tests: fuel, vertical and lateral acceleration, wheel slip, and drawbar pull  
Fuel consumption measurements for RAC  
Designed Spryte bracketry (several items)  
Modified and calibrated a temperature sensing device  
Prepared a resume of Team's capabilities for M.R.D.C.
- October Redesigned Spryte trackslip brackets  
Redesigned aluminum truss  
Rewired fuel flowmeter  
Fabricated a small calibrated fuel tube  
Assisted in Power Wagon tests  
Assisted as test photographer  
Modified and calibrated an air speed and direction indicator
- November Completed fuel, bollard-pull, track slip tests on Spryte  
Measured cushion pressure on Hover Truck  
Installed instrumentation on Hover Truck for drawbar pull and trafficability tests  
Modified six intrusion detectors  
Repaired three soil moisture meters and one lab balance  
Submitted an electro-osmosis proposal  
Modified drawbar pull field control units  
Designed a drawbar pull data reduction monogram
- December Ran drawbar pull and rolling resistance tests on Hover Truck while varying air pressure  
Reduced above data  
Measured vibration of vehicle and driver on Power Wagon  
Started to construct a photo evaluator

1965

- January    Reduced vibration data  
            Repaired a shearmeter and penetrometer  
            Fabricated new central control unit  
            Submitted electro-osmosis proposal to ARPA  
            Designed an instrumented vegetation bumper  
            Repaired six soil moisture meters
- February    Completely built two 15½ lb. transducers  
            Disassembled Hover Truck  
            Performed drop test on front axle of Power Wagon  
            Built a shaker table
- March       Studied simplification of developing recordings in field  
            Built portable continuous developer  
            Adapted penetrometer and shearmeter to CSU equipment, tested  
                    and demonstrated it to MRDC  
            Measured soil strength for anticipated XM-561 tests  
            Preliminary tests on vegetation bumper  
            Built instrumentation platform
- April       Field testing of vegetation bumper and developing test  
            Trained Thai engineer in field operations  
            Rolligon drawbar pull and rolling resistance tests  
            Built low air pressure meter  
            Assisted in gun barrel temperature measurements  
            Modified vibration table  
            Completed and tested M-116 wheel cams
- May          Modified vegetation bumper for vertical force  
            Rolligon drawbar pull and rolling resistance tests and soil tests  
            Gun barrel temperature experiments conducted  
            Experiment with WES in soil measurement repeatability  
            Designed sled for soil meters  
            Built additional drawbar pull transducers  
            Modified wheel cams  
            CSU engineering assistant returned to USA
- June        Prepared for XM-561 field tests  
            Modified calibration boxes  
            Put shelf in Land Rover  
            Fabricated brackets for XM-561: accelerometers (6), steering  
                    torque transducer, pitch and roll cams for wheel slip, and  
                    also fuel consumption piping.  
            Fabricated same bracketry for 3/4 ton truck  
            Assisted in XM-561 drawbar pull and rice paddy tests  
            Experimented with direct readout of soil measurements
- July        Completed pack frame fatigue tests  
            Soil tests at Bangpu  
            Completed XM-571 track slip cam hardware  
            Built three transducers for vegetation bumper  
            Replacement for CSU junior research engineer arrived in Bangkok  
                    and CSU instrumentation engineer returned to USA

August      Provided vegetation test instrumentation  
              Calibrated three transducers  
              Studied optimizing force transducers  
              Completed M-116 instrumentation  
              Tested M-116 drawbar pull, rolling resistance and trafficability  
              Built six fuel consumption tubes  
              XM-571 articulation joint instrumentation

The above outline of accomplishments shows that the instrumentation team performed a rather wide range of tasks. The major portion of the work load, however, was connected with vehicle testing. For this reason only the details of tasks involving the design and operation of instrumentation systems for research and development related to vehicular trafficability will be reported herein.

During the contract period the Colorado State University Thailand Trafficability Instrumentation Team instrumented and assisted with trafficability tests of the following vehicles:

1. Dodge Power Wagon
2. Vickers Hover Truck
3. M 37 3/4 ton truck
4. Spryte
5. XM-561
6. Rolligon
7. M-116
8. XM-571

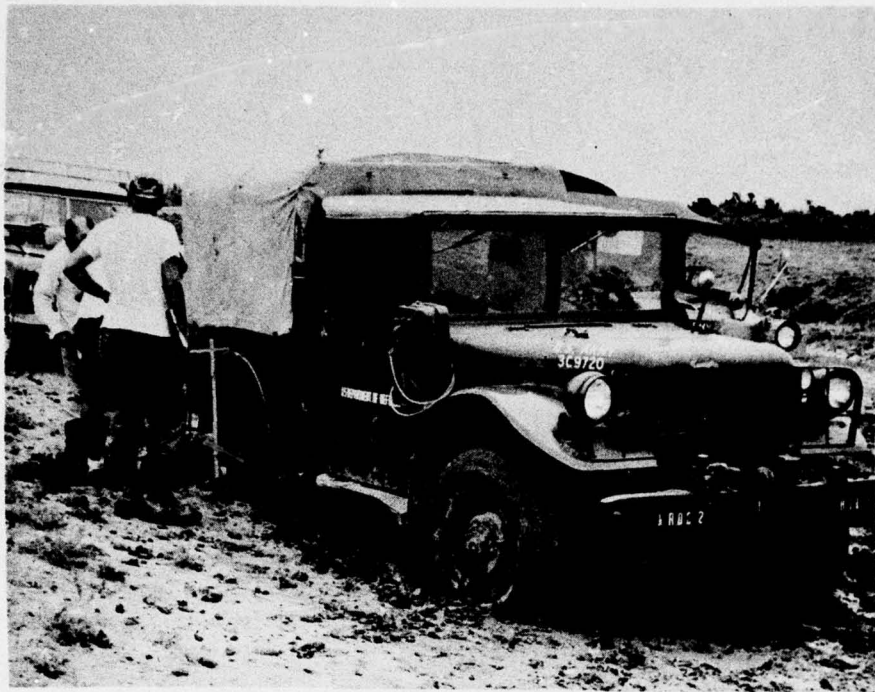
Test pictures of these vehicles are shown in Figures 1 through 8.



*Figure 1. Dodge Power Wagon Equipped with Terra Tires*



*Figure 2. Vickers Hover Craft*



*Figure 3. M 37 3/4 Ton Truck*



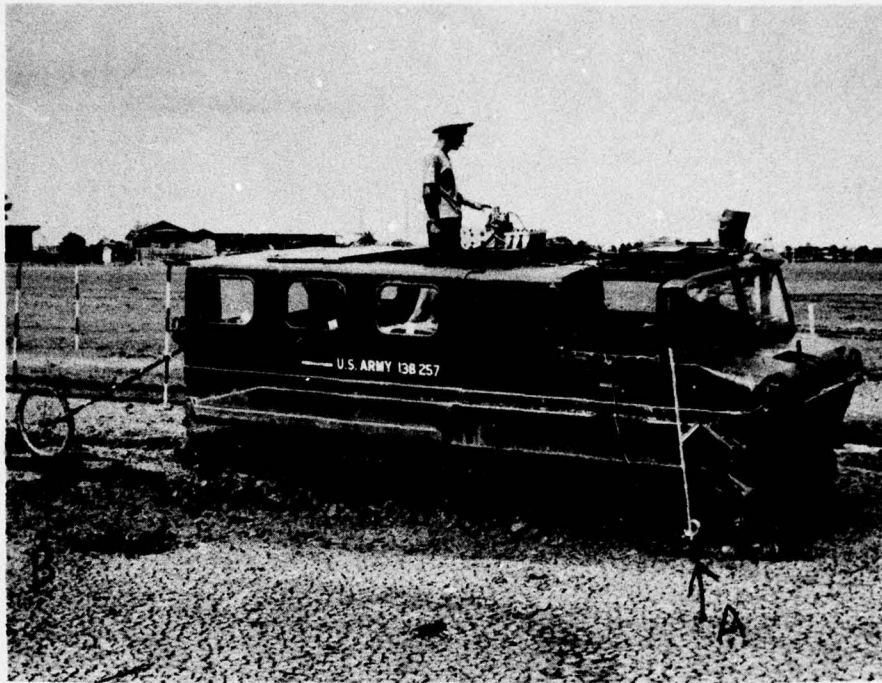
*Figure 4. Spryte*



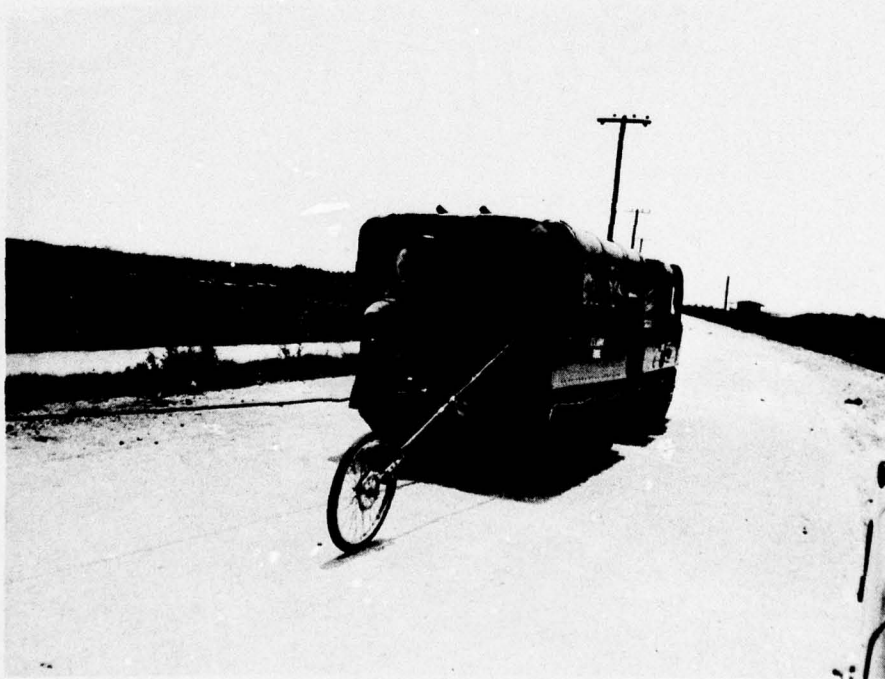
*Figure 5. XM 561*



*Figure 6. Rolligon*



*Figure 7. M-116*



*Figure 8. XM-571 Articulated Vehicle*

## INSTRUMENTATION AND MEASUREMENT SYSTEMS FOR VEHICLE TESTING

### Introduction

Instrumentation and associated bracketry was designed for making the following measurements:

1. Fuel consumption
2. Drawbar pull, bollard pull and rolling resistance
3. Track and wheel slip
4. Vehicle roll, pitch and yaw
5. Vehicle and operator acceleration
6. Vegetation impedance

Some special problems were encountered in recording the output from transducers for making the above measurements. These problems will be discussed in a special section on recording systems.

## Fuel Consumption

Early fuel consumption tests were measured using standard flow meters. The unreliability of these meters was a constant source of trouble. As a result the system shown in Figure 9 was used in later tests. The system was nothing more than a fuel container with a graduated cylinder to indicate the fuel level. This system provided a simple reliable method for determining average fuel consumption.



*Figure 9. Calibrated Fuel Can  
Installed on Dodge Power Wagon*

### Drawbar Pull, Bollard Pull and Rolling Resistance

Drawbar pull tests for the test vehicles were performed as indicated in Figure 10. The load for the test vehicle was supplied by towed vehicles. The tow cable was connected to the test vehicle through two tension load cells. The signal from one of the load cells was recorded by an oscillograph. The second load cell was included so that the drawbar pull magnitude could be observed on a meter in the test vehicle.

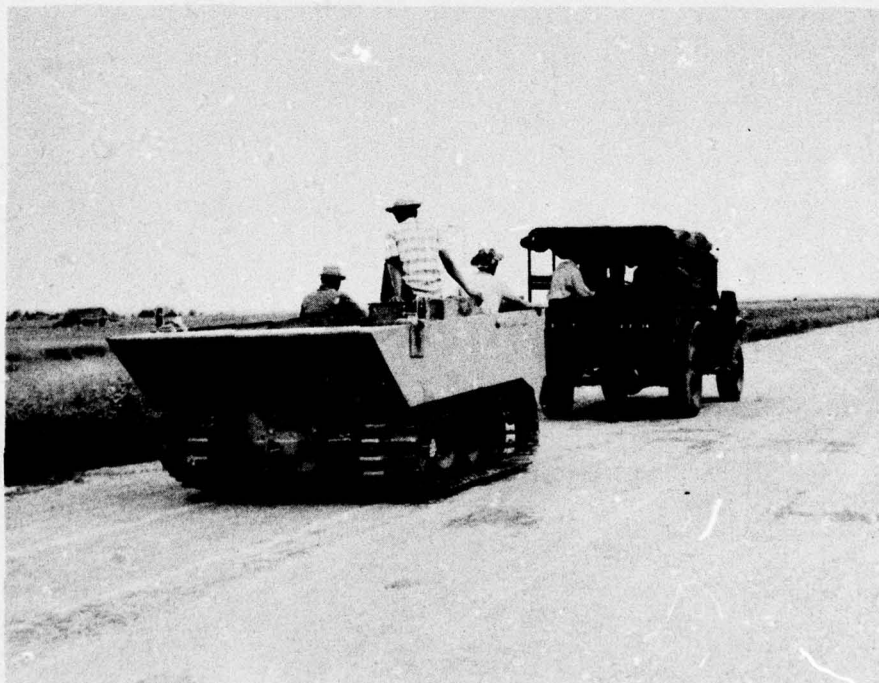
The force exerted by a floating vehicle anchored to a stationary point by a cable is known as bollard pull. The standard load cells were connected between the tow cable and the stationary point to measure the force.

Rolling resistance tests were performed as indicated in Figure 11. The load cells were used in the same manner described above.

The general design of the tension load cells used is shown in Figure 13. A tubular construction was used as shown in Figure 12. This construction was used since the cross sectional area where the strain gages were attached (see Figure 13) could be greatly reduced without too much loss of lateral rigidity. The dimensions of the machined sections were adjusted as shown in Figure 12 so that the axial stress at the rated loads was approximately constant for all of the load cells. This in turn provided an approximately constant output voltage from all the cells at their rated loads (providing the same type of strain gages were used).



*Figure 10. Drawbar Pull Test on the XM-561*



*Figure 11. Rolling Resistance Test on the Spryte*

P.U. RATING	I. D.	O. D.	WALL THICKNESS	FILLET
500 #	0.500 <sup>-0.001</sup> <sub>+0</sub>	0.524 <sup>-0</sup> <sub>+0.001</sub>	0.012"	$\frac{3}{8}$ " R
1000 #	0.625 <sup>-0.001</sup> <sub>+0</sub>	0.663 <sup>-0</sup> <sub>+0.001</sub>	0.019"	$\frac{3}{8}$ " R
2500 #	0.625 <sup>-0.001</sup> <sub>+0</sub>	0.716 <sup>-0</sup> <sub>+0.001</sub>	0.0455"	$\frac{1}{4}$ " R
5000 #	0.625 <sup>-0.001</sup> <sub>+0</sub>	0.797 <sup>-0</sup> <sub>+0.001</sub>	0.086"	$\frac{1}{4}$ " R
10000 #	0.625 <sup>-0.001</sup> <sub>+0</sub>	0.938 <sup>-0</sup> <sub>+0.001</sub>	0.1565"	$\frac{3}{16}$ " R

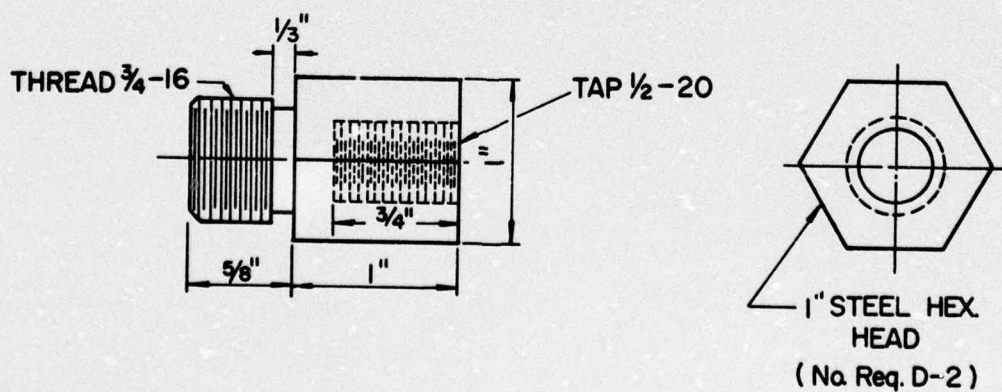
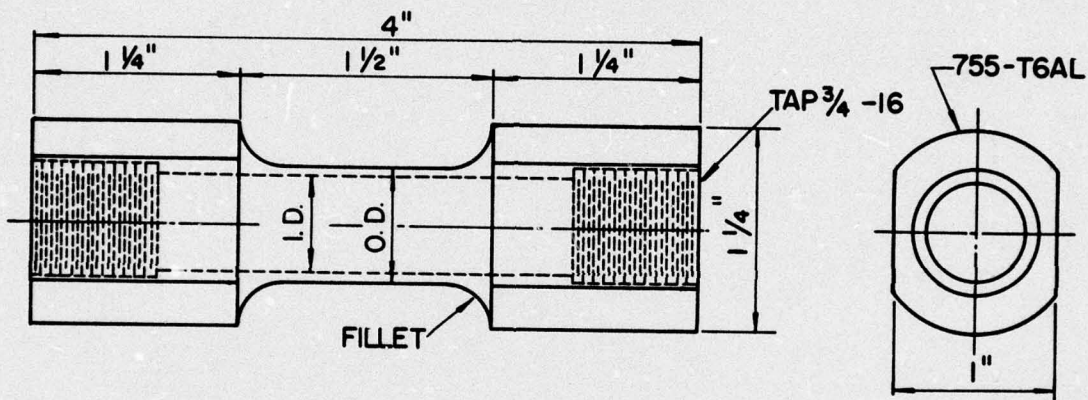
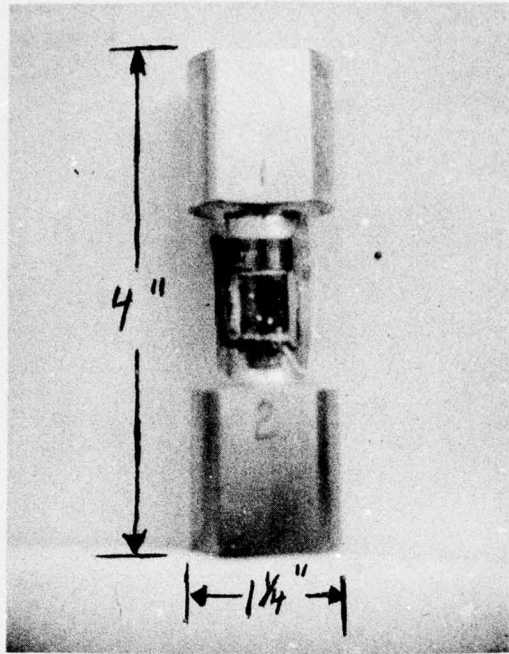
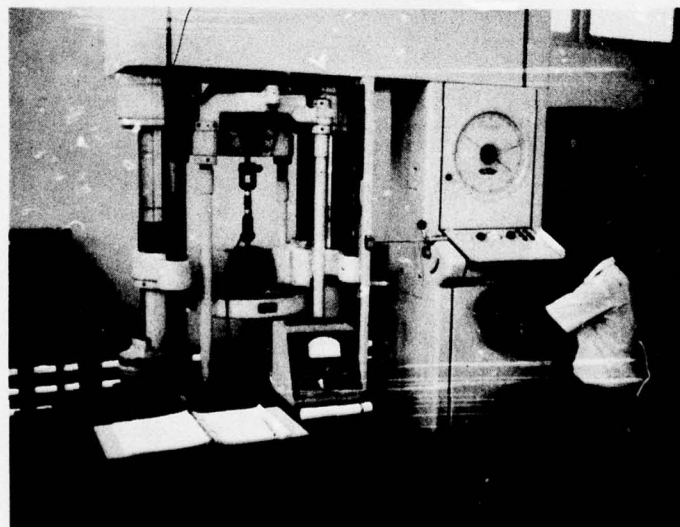


Figure 12. Detailed Drawing of Tension Load Cells



*Figure 13. Strain Gage Tension Load Cell  
Used for Measuring Drawbar Pull, Bollard  
Pull, and Rolling Resistance*

The tension load cells were calibrated at the SEATO Graduate School Materials Testing Laboratory. The hydraulic testing machine shown in Figure 14 was used.



*Figure 14. Calibration of the Tension Load Cells at  
SEATO Graduate School*

## Track and Wheel Slip Measurements

Track and wheel slip values were obtained from the equation:

$$i = \frac{V_t - V_v}{V_t}$$

where

$V_v$  = actual vehicle speed

$V_t$  = peripheral speed of the traction device contact surface (often termed theoretical vehicle speed).

A fifth wheel was used to obtain the actual vehicle speed. Voltage pulses from a cam-actuated micro switch were recorded (four per wheel revolution) on the oscillograph. A time base was also recorded so that the fifth wheel revolutions could be converted into terms of vehicle speed by a conversion factor.

The peripheral speed of the traction devices was obtained in the same manner. Figures 15 through 17 show the cam micro switch unit bracketry for several of the vehicles which were tested.

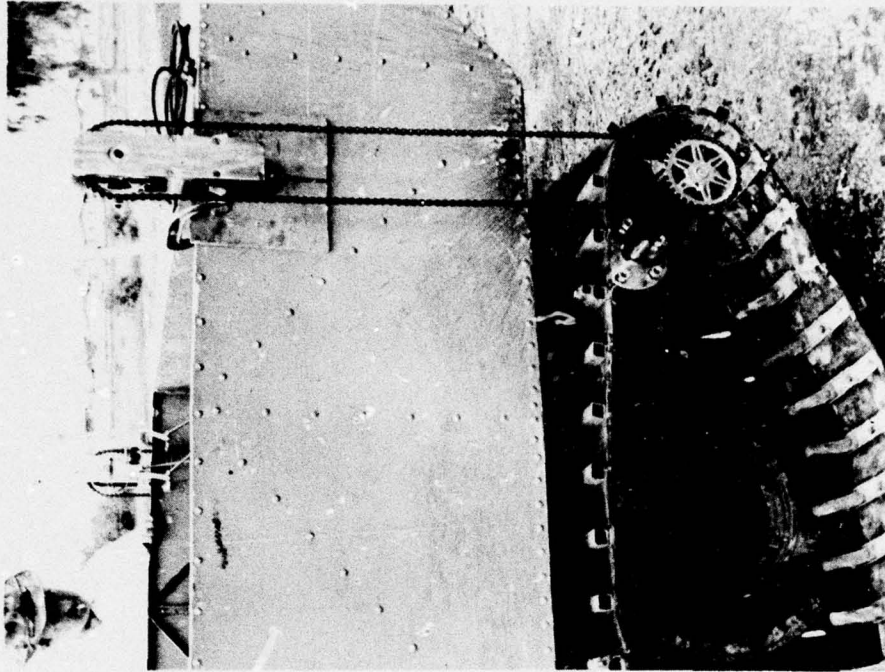


Figure 16. Sprocket Rotation Measurement Device and Bracketry on the Spryte

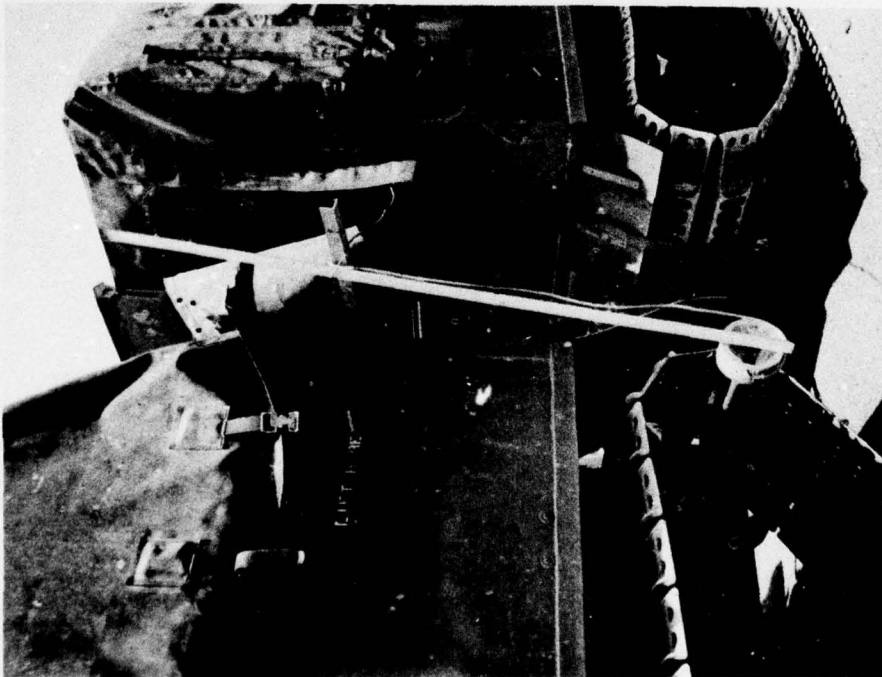
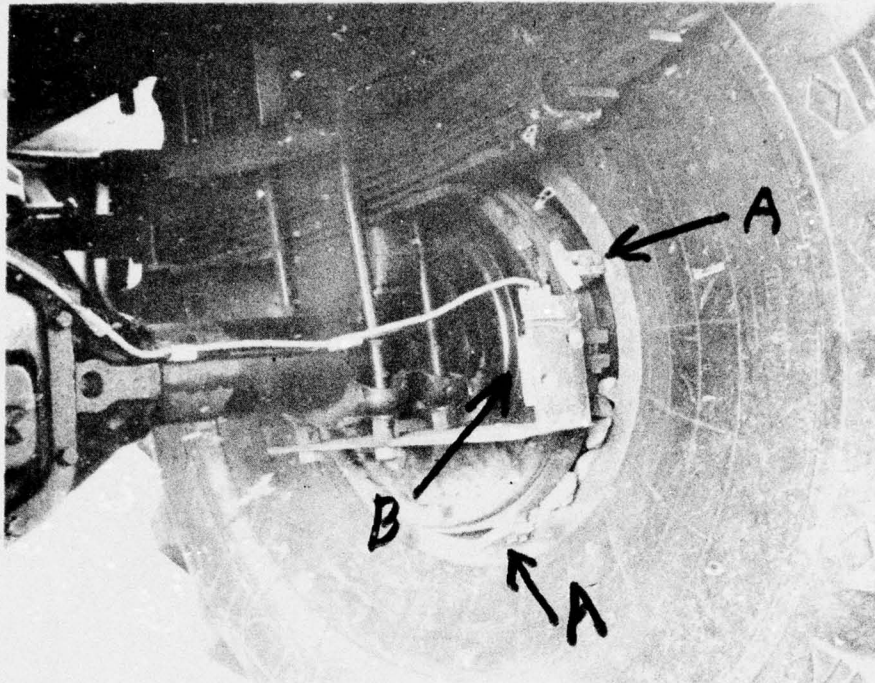


Figure 15. Sprocket Rotation Measurement Device and Bracketry on the XM-571

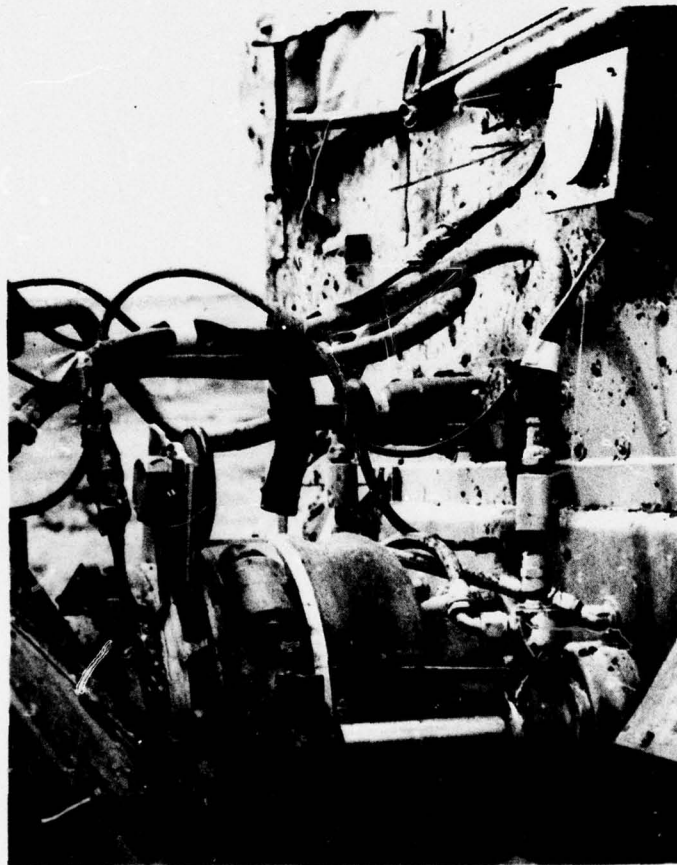


*Figure 17. Cam and Micro Switch Installation on the  
Dodge Power Wagon  
(A - Actuating Cams; B - Micro Switch Installation)*

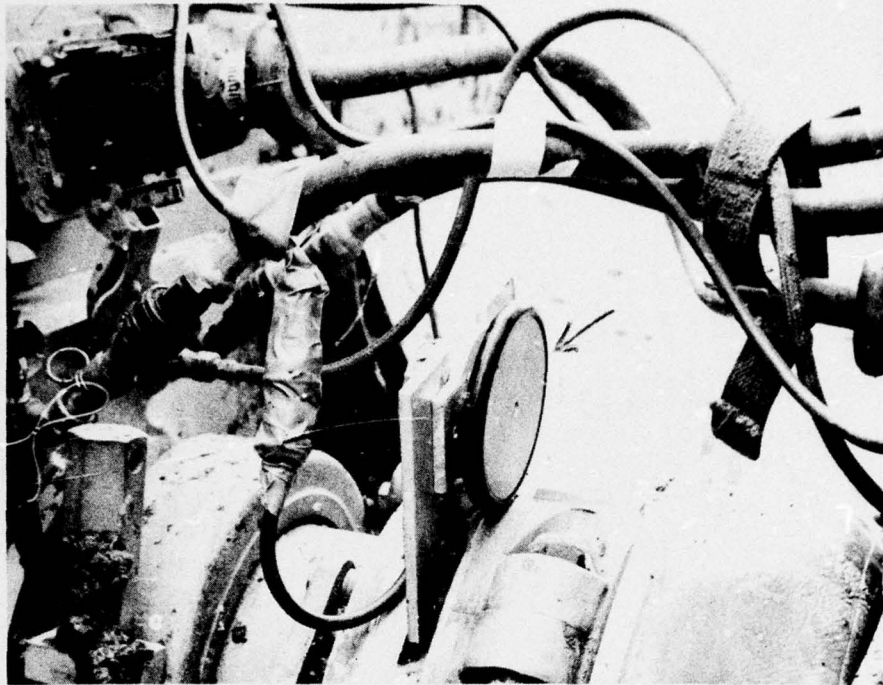
The special chain driven cam and micro switch unit used on the Spryte (Figure 16) was designed to eliminate problems associated with mud buildup in the standard unit used (Figure 15). The design proved successful.

### Vehicle Roll, Pitch, and Yaw Measurements

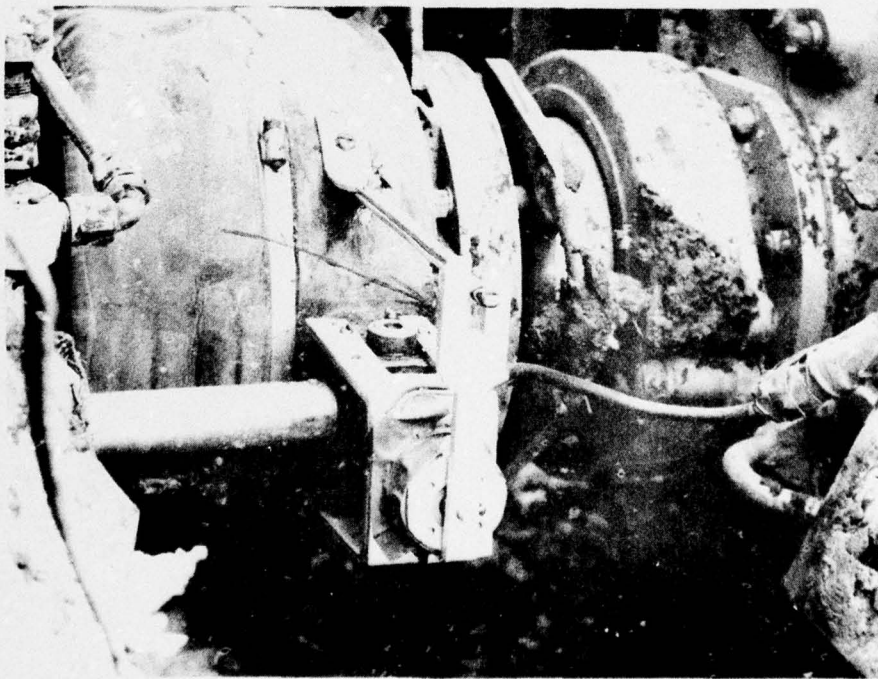
On articulated vehicles such as the XM-571 it is of interest to know the relative position of the units as it traverses various terrains. The three degrees of freedom (roll, pitch and yaw) were measured by means of precision potentiometers. The potentiometer bracketry for the three measurements are shown in Figures 18, 19, and 20.



*Figure 18. Yaw Angle Measurement Unit Between the Front and Rear Units of the XM-571 (Upper Right Hand Corner)*



*Figure 19. Roll Measurement Unit Between the Front and Rear Units of the XM-571*



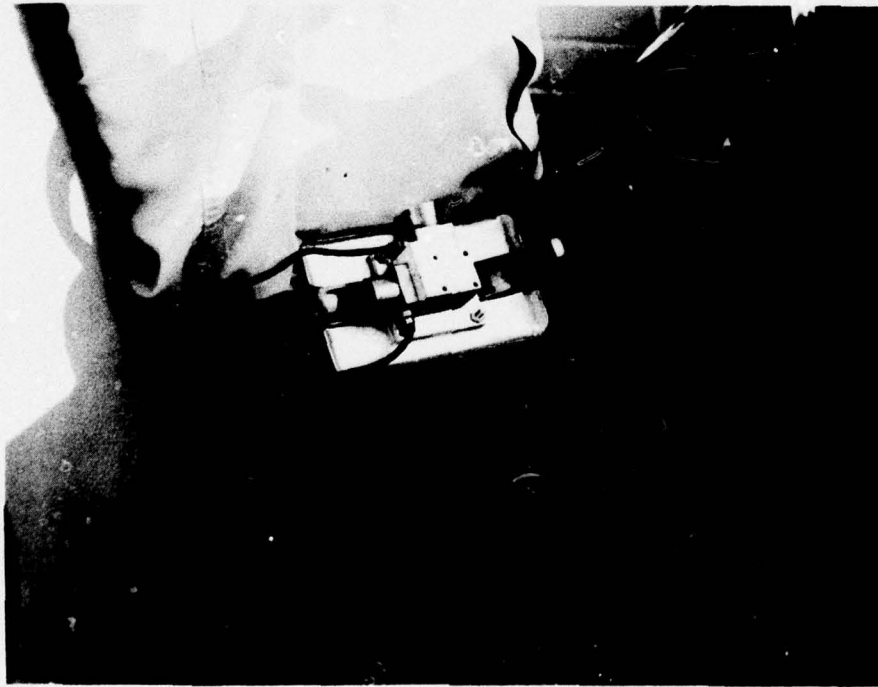
*Figure 20. Pitch Measurement Unit Between the Front and Rear Units of the XM-571*

## Vehicle and Operator Acceleration Measurement

Acceleration measurements were made at various points on several of the vehicles tested. Acceleration measurements on vehicle operators (at the driver's waist) were also made. Standard accelerometers were used so the main instrumentation problem connected with these measurements involved the design and construction of bracketry for mounting the accelerometers.

A special belt shown in Figure 21 was designed to monitor vertical and lateral accelerations at the waist of the vehicle operator.

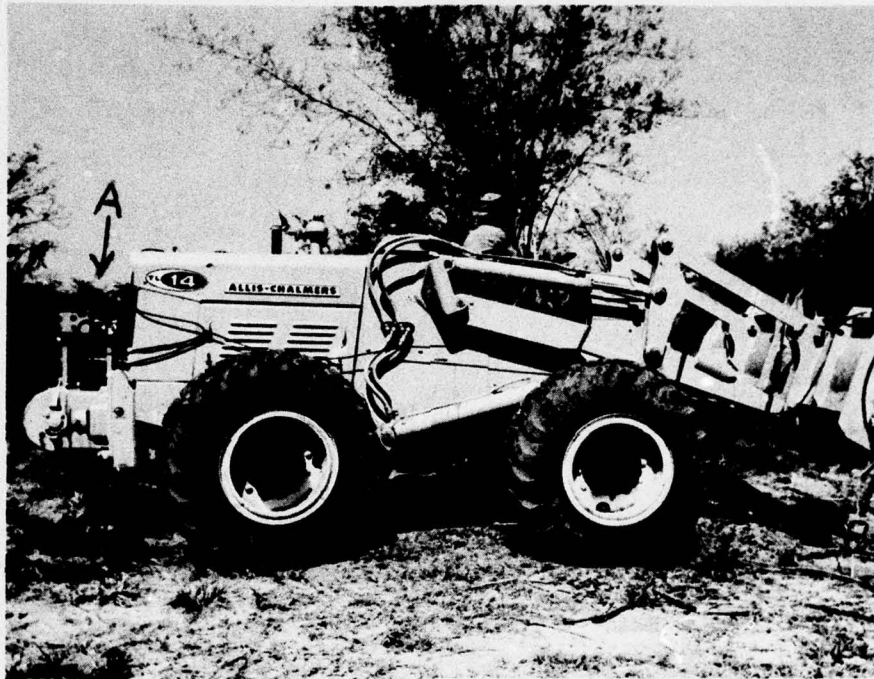
Acceleration was recorded at randomly selected times as well as points where the ride was roughest. This was done to obtain information regarding the complete vibration spectrum as well as the maximum vibration level.



*Figure 21. Belt for Monitoring Vertical and Lateral Accelerations at the Vehicle Operator's Waist*

## Vegetation Impedance Measurements

A vegetation bumper was designed to measure vegetation resistance to vehicle motion. The bumper was mounted on the blade of an Allis Chalmers TL 14 as shown in Figure 22 and 23.



*Figure 22. Vegetation Bumper Installation on an Allis Chalmers TL 14 Tractor (A - Recorder System; B - Vegetation Bumper)*

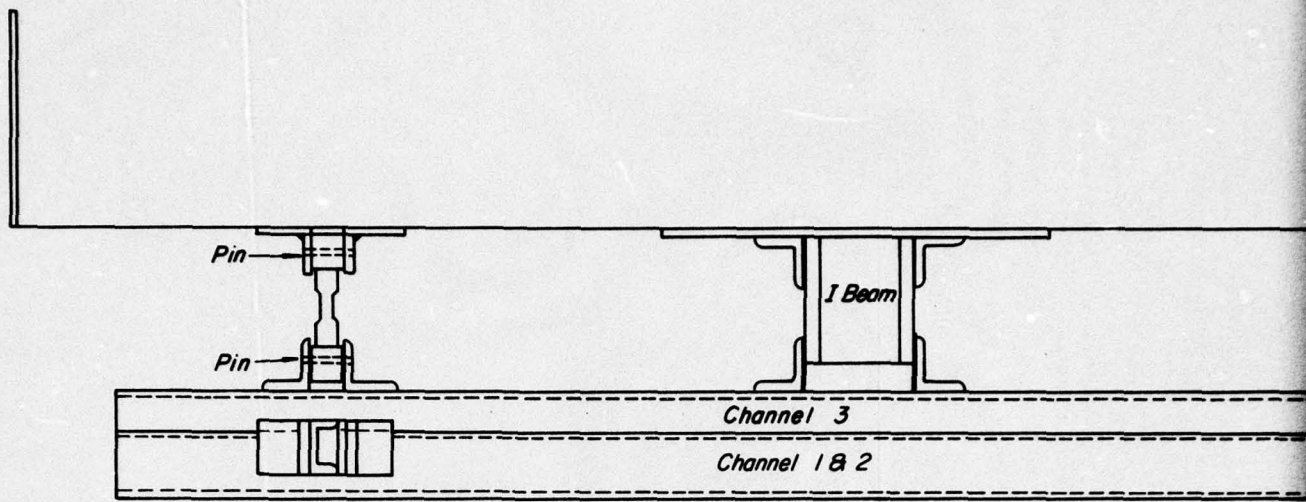
The scraper blade could be raised and lowered so that vegetation impedance could be measured from ground level up to a height of six feet.

The horizontal load on the vegetation bumper was resisted by two compression transducers (rated load = 15,000 pounds each). Early tests indicated that both the vertical components of force on the vegetation bumper was also significant in determining the vegetation impedance due to deflection of the vegetation as it passed under the bar (see Figure 23).



*Figure 23. Small Tree Being Deflected by  
Vegetation Bumper  
(A - Horizontal Force Transducer)*

The vertical member of the vegetation bumper frame was instrumented to measure the vertical forces on the bumper as indicated in Figure 24.



SECTION A - A

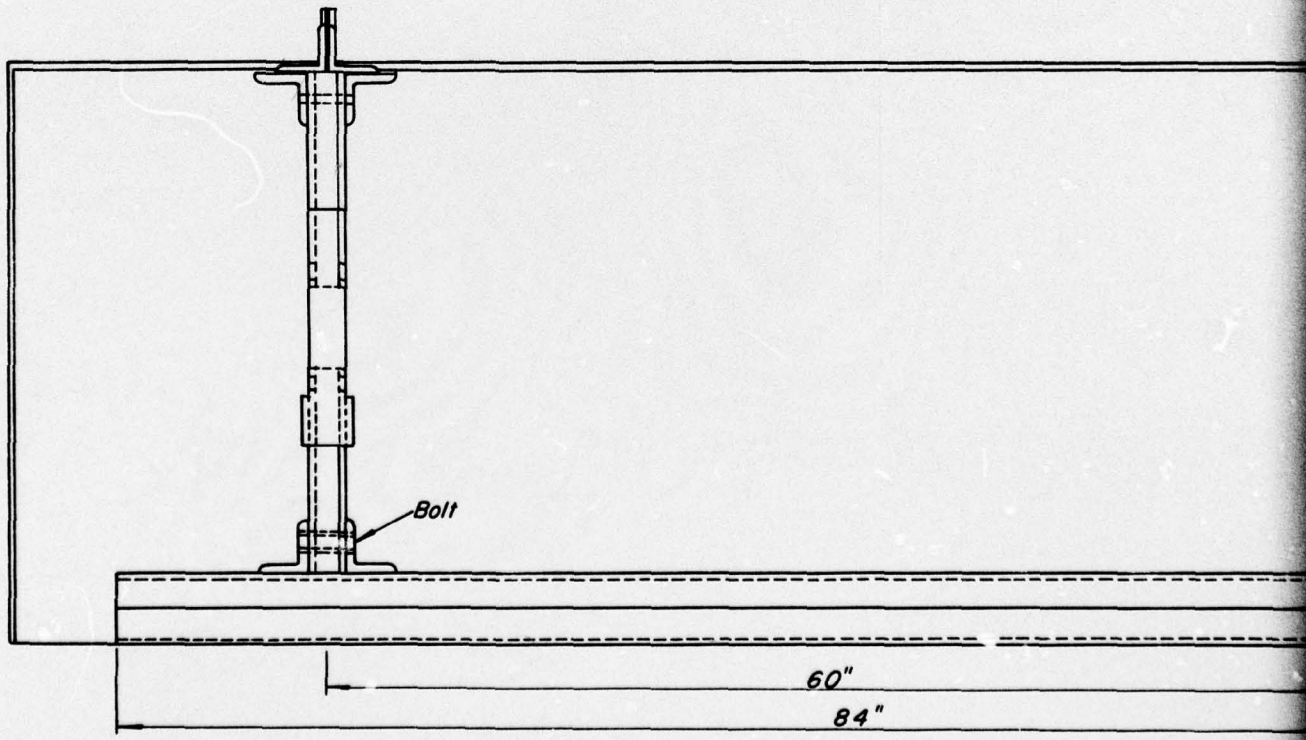
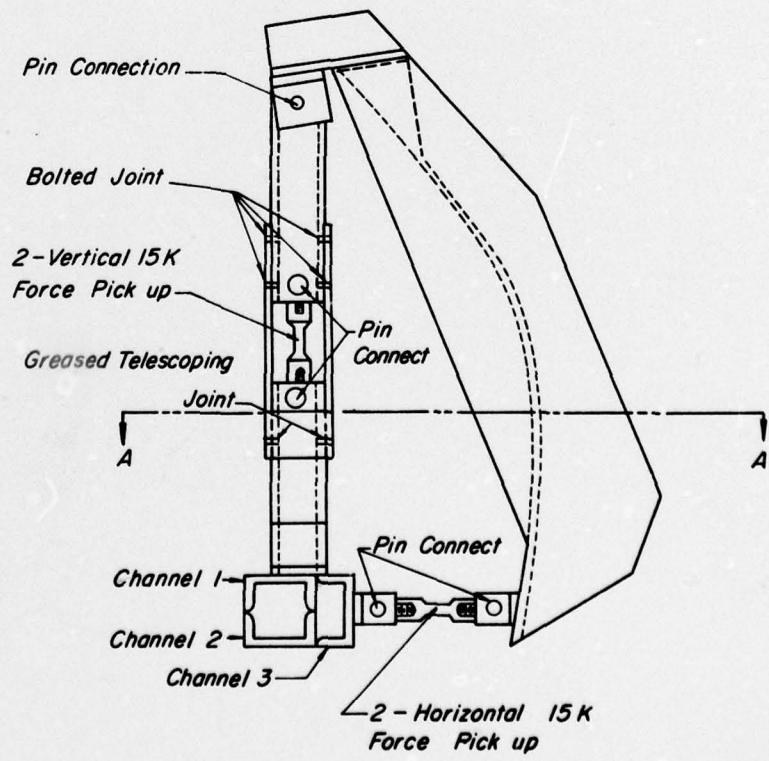
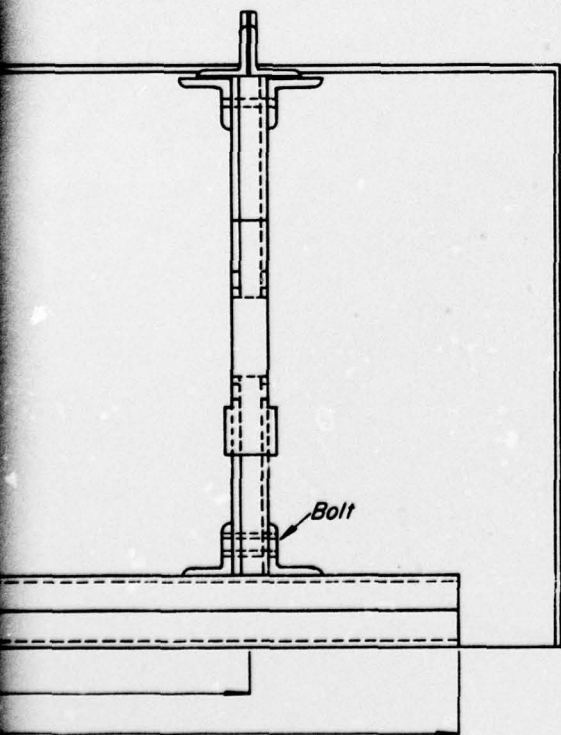
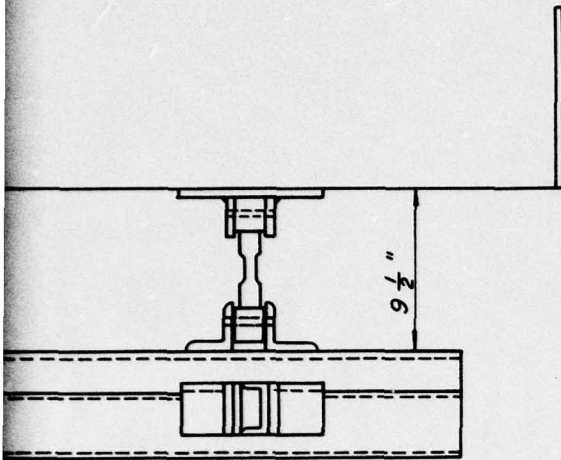


Figure 24. Vegetable Bumper Frame Design for Mo



Design for Measuring Vertical and Horizontal Forces

## RECORDING AND CALIBRATION SYSTEM

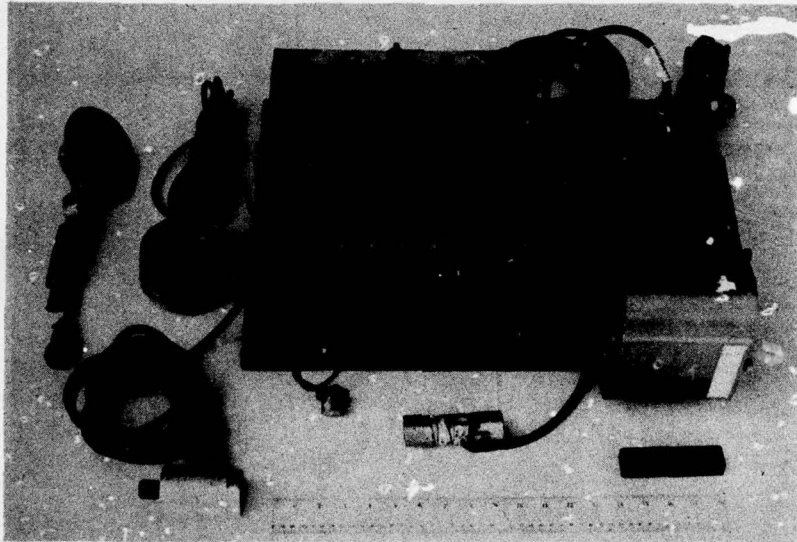
### Recording System

The recording system was designed and fabricated by H. B. Leiby. It includes a 12-channel, light beam, oscillograph; a bridge balance-calibration unit; and a battery pack. The battery pack (six 6V No. 918 lantern batteries) provides d.c. power for transducer excitation.

A separate battery pack consisting of two 12 volt automotive batteries is used for driving the oscillograph when 24 volt power is not available on the test vehicle.

The recording system was mounted on a common base as shown in Figure 25. The scale at the bottom of the photograph shows that the system is quite small considering its six-channel capability. Its small physical size coupled with the use of d.c. (battery) power makes this an ideal recording system for vehicle mobility testing in remote areas for the following reasons:

1. The system can almost always be carried on the test vehicle, thus eliminating the need for an instrument vehicle.
2. The use of battery power eliminates the need for an a.c. power supply. The use of an engine-driven power supply would require additional space and be an additional source of trouble.



*Figure 25. The CSU Recording System Connected to a Variety of Transducers*

### Recording Oscillograph

The outputs from the transducers were recorded by a Century Model 409-X, twelve-channel oscillograph. This unit proved ideal for field testing. It is an extremely rugged instrument and requires a minimum amount of maintenance even in a tropical environment such as Thailand. This oscillograph incorporates the use of light beam galvanometers for recording. The chart paper must therefore be developed. The developing is normally performed in a laboratory developer such as the Viewlex Model A Oscillomatic. It was found, however, that field developing was necessary to allow quick detection of mechanical or electrical failures in the data gathering systems. The direct print conversion unit for the Century 409-X Oscillograph was not suited for the Thailand environment according to the manufacturer. Kodak photosensitive paper proved unsuitable because the radiation emitted by the galvanometers was not sufficiently intense in the ultraviolet range to affect the paper.

A field developer was therefore assembled by the CSU Instrumentation Team. The tank and roller system from a Viewlex Oscillomatic developer was installed in a light weight frame. The rollers were driven by hand cranks to eliminate the need for an a.c. power unit. The developing solutions used in the laboratory were used in the field developer. The developed recording paper was air dried. The field developer proved successful. It was light enough to be carried by one man and was capable of developing chart paper at a rate of six inches per second.

### Bridge Balance-Calibration Unit

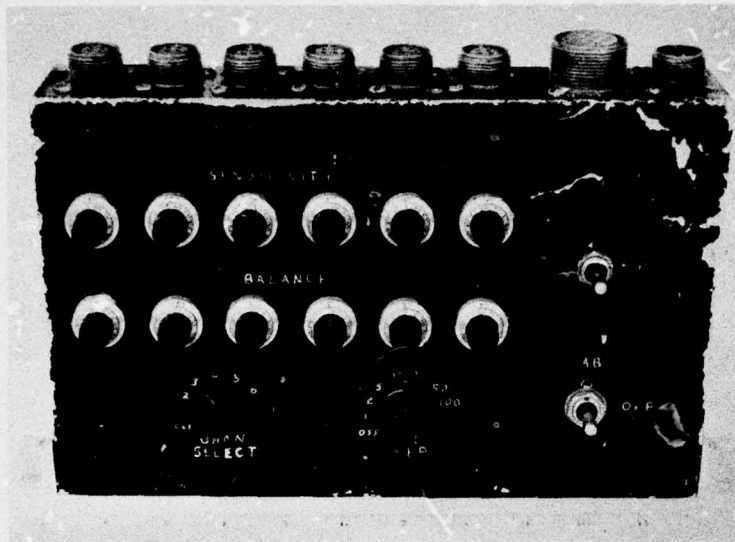
The bridge balance-calibration unit was designed as a companion instrument to the Century Oscillograph. It provides a simple and accurate method for balancing and calibrating bridge circuits from resistance-type transducers. Potentiometer transducers and switching circuits can also be powered and monitored through the bridge balance-calibration unit. This is accomplished through use of external resistor networks located within the Amphenol input plug from the potentiometer or switch.

Front and rear views of the unit are shown in Figures 26 and 27. The enclosure is standard unit. The hole layout for the potentiometers and switches is shown in Figure 28.

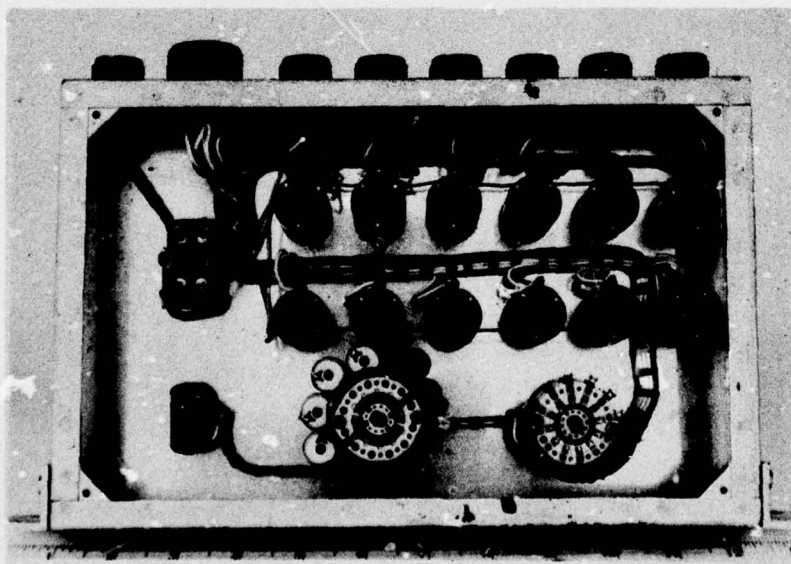
The wiring diagram for the bridge balance-calibration unit is shown in Figure 29. From the wiring diagram it can be noted that any one of the seven precision resistors can be placed in parallel with bridge legs AB or AC on any channel by means of the channel selector switch S-1, the directional switch S-2, and the calibrate switch S-3. Placing a resistor in parallel with a bridge leg provides an equivalent strain when the bridge resistors are SR-4 strain gages. The equivalent strain method provides a very convenient method of calibration which is described in the next section.

A list of materials for the bridge balance-calibration unit is as follows:

<u>Quantity</u>	<u>Description</u>
1	aluminum box, 2"x7"x11"
6	plug amphenol (4 wire), AN-310-1452S
1	plug amphenol G1-1 (14 wire), AN-3106-20-27S



*Figure 26. Front View of Bridge Balance-Calibration Unit*



*Figure 27. Rear View of Bridge Balance-Calibration Unit*



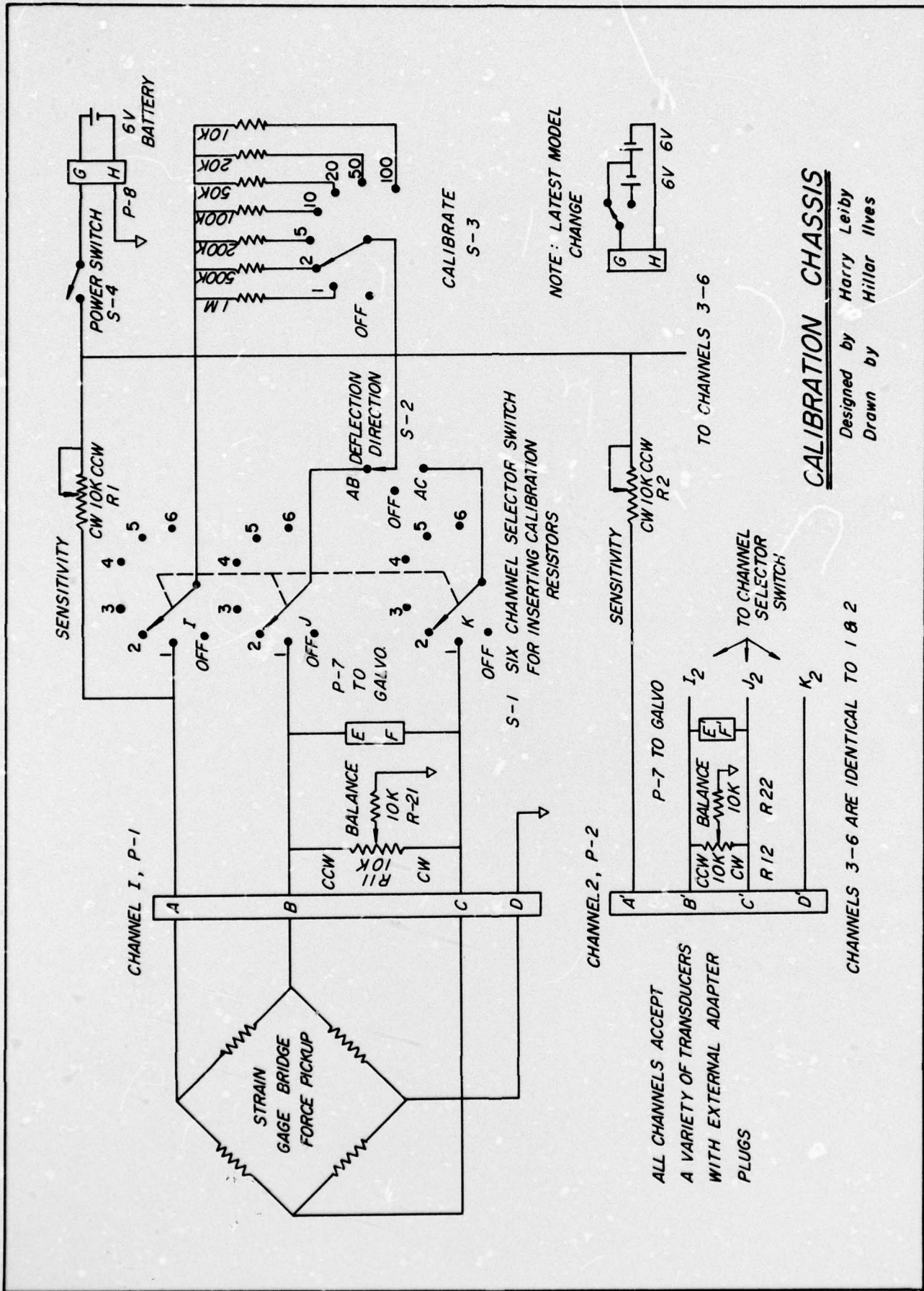


Figure 29. Bridge Balance-Calibration Unit Wiring Diagram

<u>Quantity</u>	<u>Description</u>	(continued)
12	No. 7221, 10k $\pm$ 3%, Helipot, Beckman Industries, Fullerton, California	
1	2 pole, 12 position switch	
1	3 pole, 12 position switch	
1	DPDT switch	
1	SPDT switch	
1	plug amphenol 14S-2P (4 wire). AN-3106-14S-2P	
7	resistors $\pm$ .1%, 10k, 20k, 50k, 100k, 200k, 500k, 1m	

The use of external networks installed in the Amphenol connecting plugs from potentiometers and switching transducers has been mentioned previously. These networks are shown in Figures 30 and 31. The resistor  $R_1$  in the switching external network is selected to limit the galvanometer current; the balance potentiometer is used to set the desired galvanometer deflection. The resistor  $R_1$  in the potentiometer external circuit is also selected to limit the galvanometer current. The variable resistor  $R_2$  is a course gain control; fine gain adjustment is controlled by the gain potentiometer in the bridge balance-calibration unit. Proper damping resistors must be selected and inserted between pins B and C on both of the above networks.

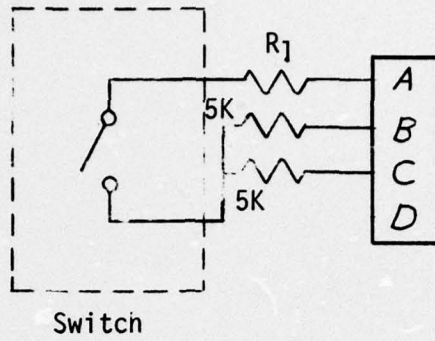


Figure 30. External Network for Switching Transducer

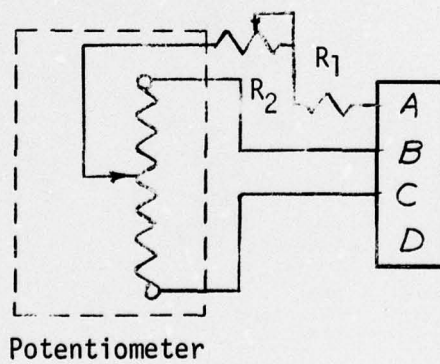


Figure 31. External Network for Potentiometer Transducer

### Calibration Procedure

Calibrations of SR-4 type transducers were performed by the equivalent strain method. After the transducer was connected to a suitable monitoring device such as an Ellis Bridge Amplifier, the bridge was balanced. The transducer was then placed in a loading machine and subjected to its full rated load. The gain on the amplifier was then adjusted to obtain full scale deflection of the meter. After the load had been removed and the bridge balance rechecked, incremental loads were applied from zero to the rated load. Meter readings were recorded for each load. After the load was again removed, appropriate calibration resistors were switched into the circuit; meter readings were recorded for each resistance.

Since each of the above calibration resistor readings represents an equivalent load, calibration step readings could be superimposed on the load versus meter reading line to yield a load versus calibration-step line. The calibration step resistors in the bridge balance-calibration unit were matched to those in the Ellis Bridge Amplifier. Therefore, when a transducer was connected to the CSU recording system, equivalent loads could be simulated by switching in an appropriate calibration resistor. The gain was then adjusted to obtain proper deflection of the recording galvanometer.

An example of the steps necessary for recording an expected force of 200 to 300 pounds is as follows for a 1,000 pound transducer:

1. Balance the transducer bridge with no force applied.
2. Switch in an appropriate calibration step. From the load versus calibration step line for the 1,000 pound transducer  
Step 20 = 188 pounds.

3. Adjust the sensitivity potentiometer until the galvanometer trace deflects 1.88 inches with the calibration Step 20 switched into the bridge.
4. Switch the calibration step off and commence with the test. The sensitivity is now 100 pounds per inch deflection of the galvanometer trace.

## SUMMARY

Vehicle mobility testing in a remote tropical environment presents some very special problems. Instrumentation systems must be reliable, simple, rugged, corrosion resistant, and have a small space requirement.

The Colorado State University Instrumentation Team designed and assembled an instrumentation system which performed exceptionally well under the above conditions. The problems outlined above were minimized by taking the following steps:

1. A d.c. recording system was used to eliminate the need for an engine driven a.c. power supply.
2. A Century light beam oscillograph was used; this proved to be an extremely rugged, lightweight, reliable unit.
3. A bridge balance-calibration unit was designed and fabricated which provided a very convenient method for providing power to transducers, attenuating the output signals from the transducers, balancing the bridge circuits, and for calibration of the transducers.
4. Lightweight force transducers were fabricated from high strength aluminum to minimize corrosion problems and excessive weight.

The recording system requires very little space and can be carried on the test vehicle. The system can be utilized to monitor drawbar pull, wheel slip, vehicle velocity, acceleration, vehicle yaw, vehicle roll, and vehicle pitch.